Prospect theory under uncertainty for Assessing Global Environmental-Economic Policies

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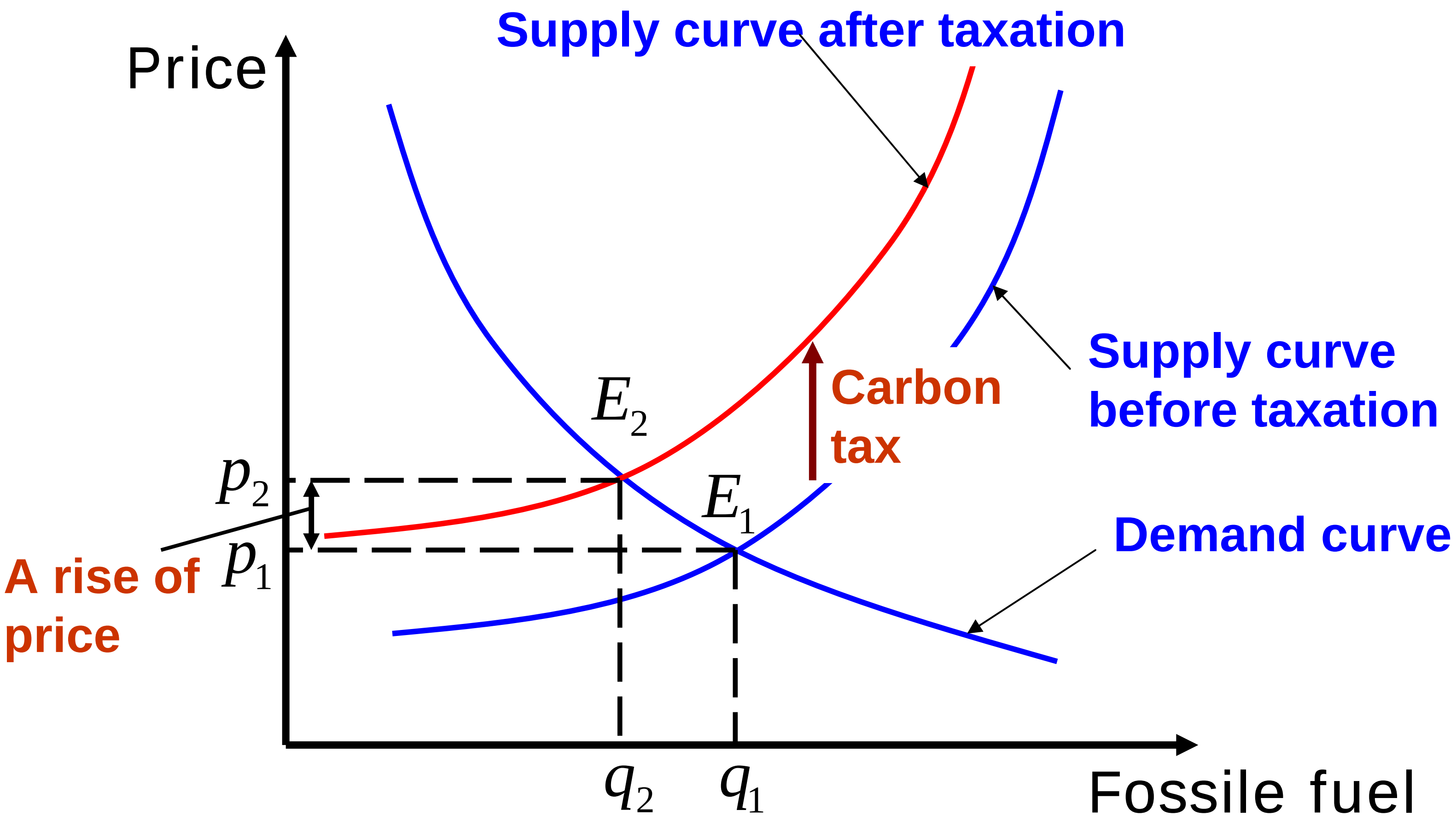
Background and introduction

- **Carbon dioxide (CO_2) emissions and the global warming problem is a kind of social dilemma.**
- **We evaluate some policies such as**
  - **Investment for the CO_2 reduction behavior**
  - **Carbon tax**
  - **Emissions trading**

  in order to meet the CO_2 emissions reduction target.
- **We take into account uncertainty for evaluating these policies.**

Carbon tax



Rise of price by introducing the carbon tax

Evaluation model (1)

Classification of industrial sectors

Sector 1	Agriculture, Forestry and Fishery / Food product
Sector 2	Fiber / pulp, wooden goods
Sector 3	Chemistry product / Petroleum production
Sector 4	Steel / Nonferrous metal / Metal
Sector 5	General machinery / Electricity machinery / Precision machinery
Sector 6	Other manufacturing industry
Sector 7	Construction
Sector 8	Transportation
Sector 9	Service
Sector 10	Others

Evaluation model (2)

- **Profit maximization**

$$\underset{x,v}{\text{Maximize}} \quad p(x,v)x - p(x,v)\left(A - M\right)x - k(x)$$

$$\text{subject to} \quad \left(I - A + M\right)x = d(p) + w$$

- **Changes of the domestic final demand**

$$d_i = d_{i0}\left(1 + \varepsilon_i \frac{p_i - p_{i0}}{p_{i0}}\right)$$

p(*): a domestic price vector
x : an output vector
v : a value-added vector
A : an input-output coefficient matrix
M : an import coefficient matrix
k(*): a CO_2 cost vector
d(*): a domestic final demand vector
w : an export vector
d_i : a domestic final demand of sector *i*
ε_i : a price elasticity of domestic for output of the sector *i*
p_i : a price of the domestic demand of sector *i*

Evaluation model (3)

- **Trading :**
  (based on Cournot competition)

$$\underset{w_i}{\text{Maximize}} \quad p_i^a(w_i)w_i - c_i w_i$$

$$\text{subject to} \quad p_i^a(w_i) = a - b(w_i + w_i^a)$$

$$c_i = p_i\left(A_i - M_i\right) + k_i \ , \ w_i \geq 0$$

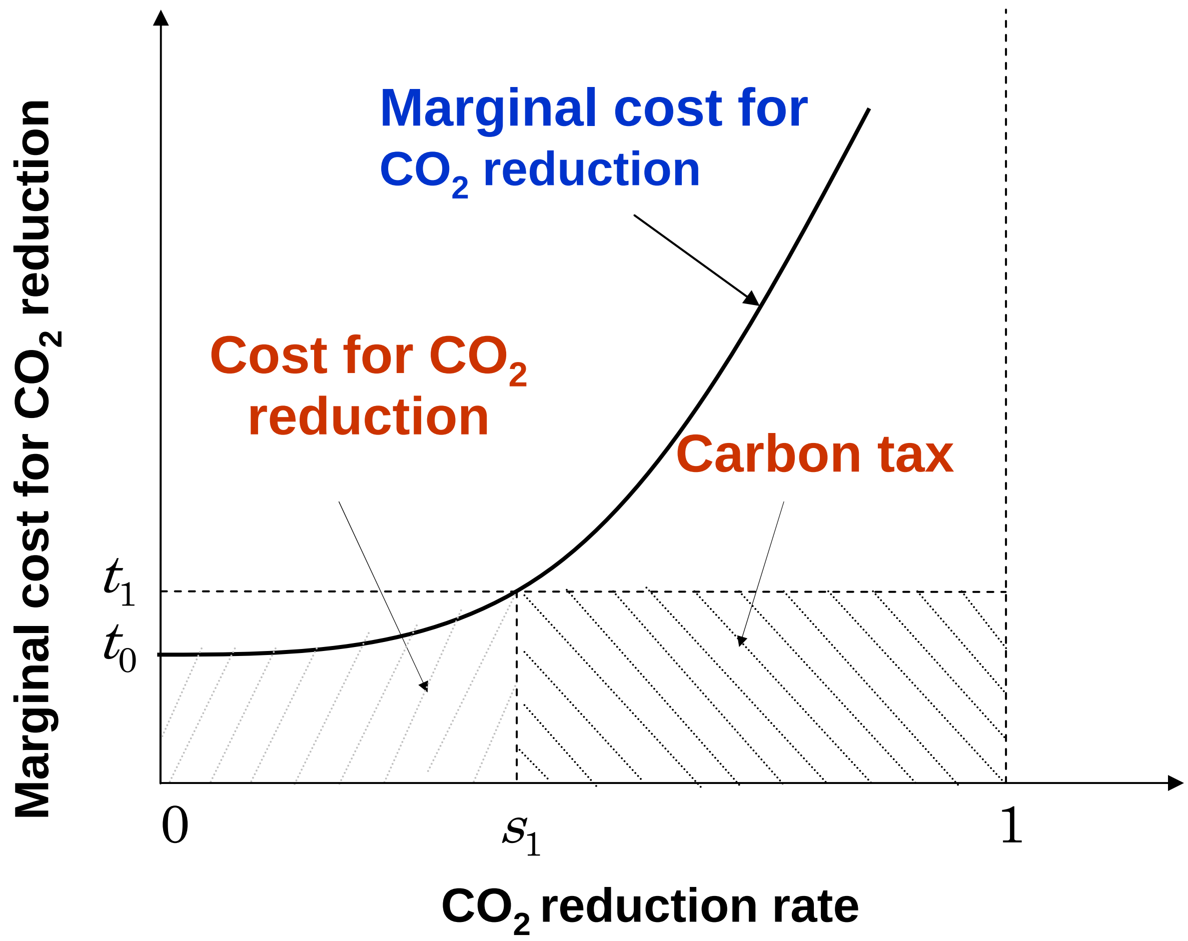
CO_2 cost minimization:
(cost to reduce CO2 plus carbon tax)

$$k(x) = \min_{t, s_i} \sum_{i=1}^{10} \left\{ \int_0^{s_i} f(s)ds + \left(1 - s_i\right)t \right\} r_i x_i$$

$$\text{subject to} \quad \sum_{i=1}^{10} \left(1 - s_i\right) r_i x_i \leq T$$

p_i^a : **import demand function of sector *I***
w_i : **export of sector *I***
a : **constant term of an import demand function**
b : **coefficient of import function**
w_i^a : **sum of export of sector *i* in the rest of the countries**
r_i : **CO_2 intensity of sector *i***
s_i : **ratio of CO_2 reduction of sector *i***
$f(*)$: **marginal cost function of CO_2 reduction**
t : **carbon tax**
T : **CO_2 emission limitation**

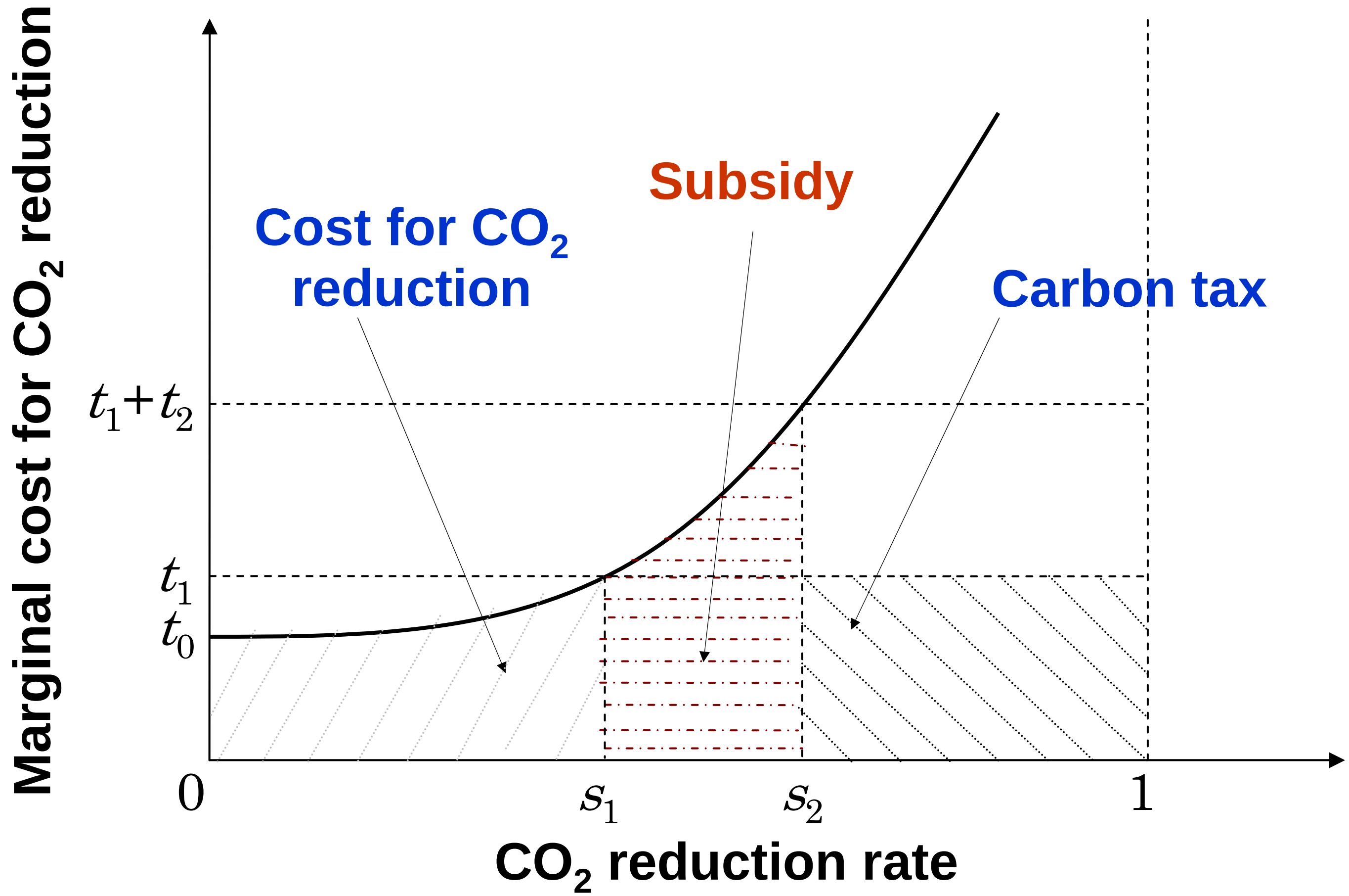
CO_2 cost : Cost for CO_2 reduction plus carbon tax



t_0: CO_2 marginal reduction cost at present

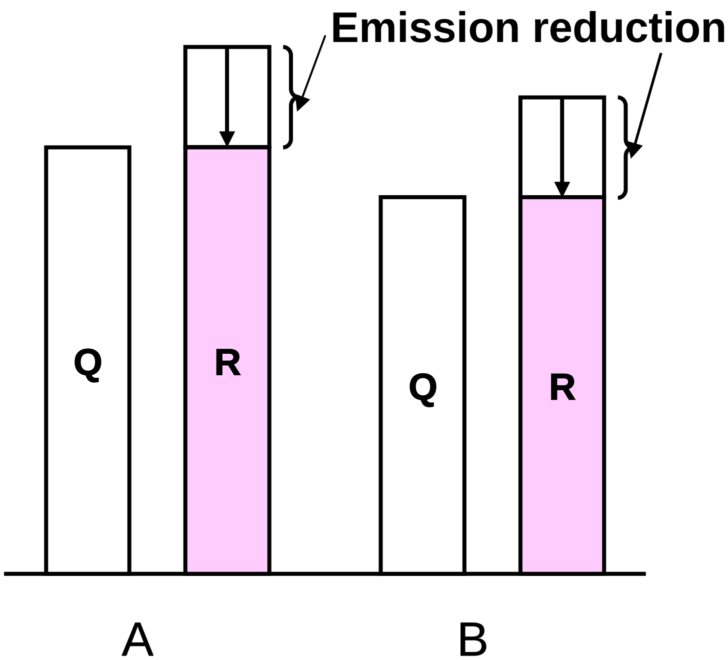
t_1: carbon tax rate

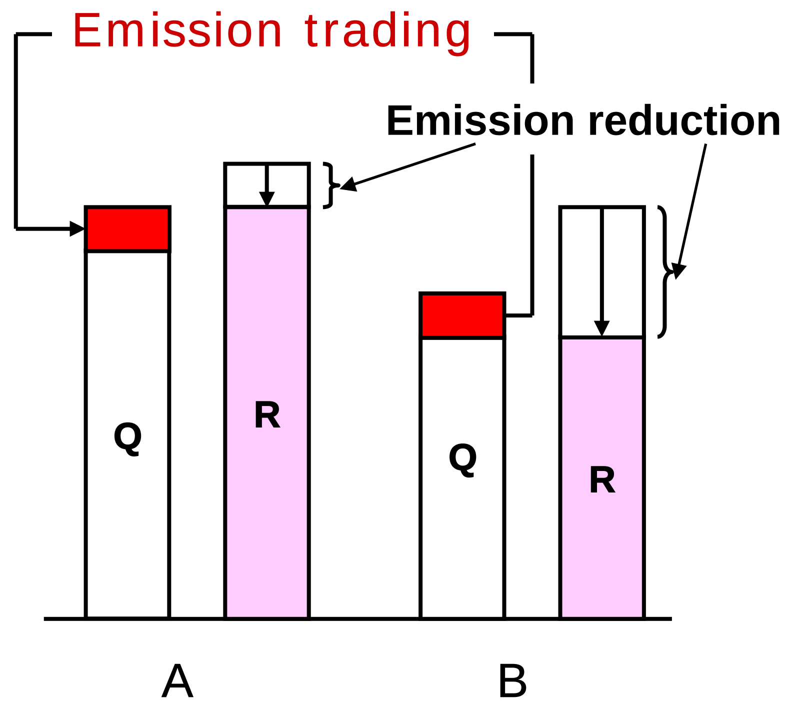
CO_2 reduction behavior, subsidy and carbon tax



t_2: subsidy for marginal reduction of CO_2 emissions

Emission trading (1)





Q: Emissions quota

R: Real emissions

Without emission trading

With emission trading

Emission trading (2)

	A Co.	B Co.	Total
Unit cost for reduction	$200	$100	-
Nec. reduction	2	2	4
Real reduction	2	2	4
Cost for red.	$400	$200	$600
Trading cost	-	-	-
Compliance cost	$400	$200	$600

Without emission trading

	A Co.	B Co.	Total
Unit cost for reduction	$200	$100	-
Nec. reduction	2	2	4
Real reduction	1	3	4
Cost for red.	$200	$300	$500
Trading cost	$150	-$150	$0
Compliance cost	$350	$150	$500

With emission trading

Prospect Theory (PT) (1)

In Prospect Theory (PT), the value of the prospect

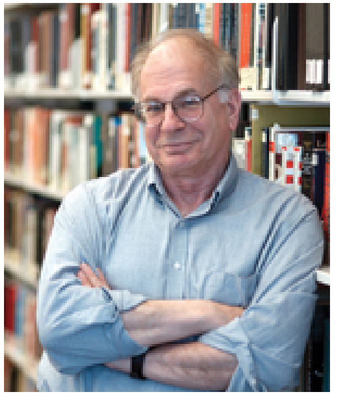
$$l = (x^1, x^2, \cdots, x^n : p_1, p_2, \cdots, p_n)$$

which yields outcome x^j **with probability** p_j **where** $j = 1, 2, \cdots, n$ **is evaluated by**

$$V = \sum_{j=1}^{n} \pi(p_j) v(x^j)$$

π **: weighting function**

v **: value function**



Prof. Daniel Kahneman (1934~)
2002 Nobel Prize in Economics

Prospect Theory (PT) (2)

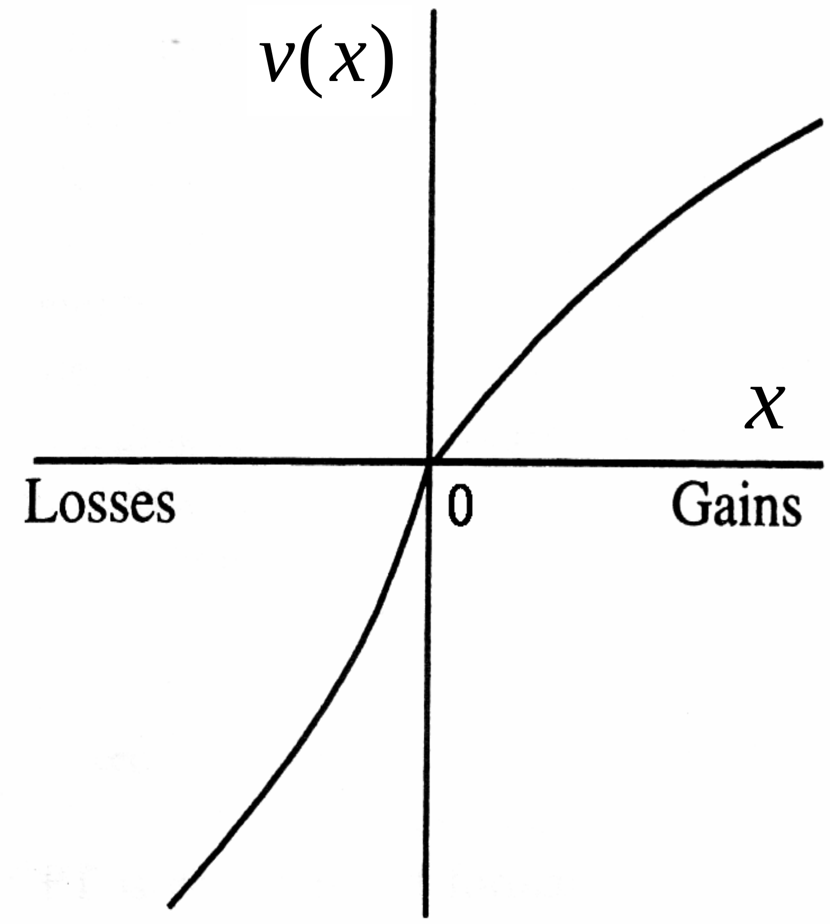
Value function is:

Concave in gain domain, convex in loss domain

→People's decision making is loss averse.

Steeper in loss domain

→The value for loss seems greater than that for the same amount of gain.



Prospect Theory (PT) (3)

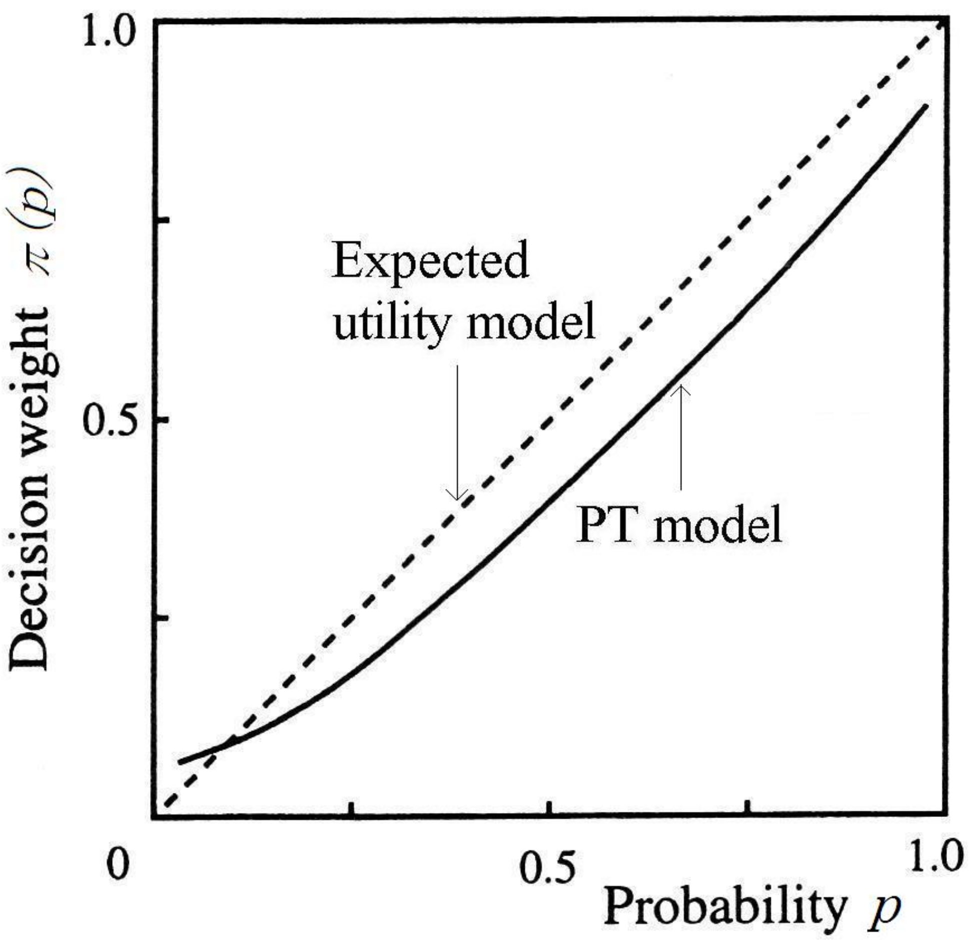
Weighting function is:

- **Convex**

→Small probability is weighted larger

→Middle or large probability is weighted smaller

- **Not defined near the end point 0 and 1**



Prospect theory under uncertainty (1)

We have developed PT under uncertainty using the basic probability of Dempster-Shafer theory.

The value of a prospect is evaluated by

$$V = \sum_{j=1}^{n} \pi'(\mu_j) v^*(B_j)$$

μ_j **: basic probability,** B_j **: set element**

π' **: weighting function for basic probability**

v^* **: value function for a set element**

With this model we could resolve the problems of evaluating alternatives with unknown probability for each event like Ellsberg paradox.

Prospect theory under uncertainty (2)

Axiom of Dominance:

In the set element B **let the worst consequence be** m_B **and the best consequence be** M_B**. For any** $B1, B2 \subset \Lambda = 2^{\Theta}$

$$m_{B1} \preceq m_{B2},\ M_{B1} \preceq M_{B2} \quad \Rightarrow \quad B1 \preceq B2$$

and

$$m_{B1} \sim m_{B2},\ M_{B1} \sim M_{B2} \quad \Rightarrow \quad B1 \sim B2$$

Prospect theory under uncertainty (3)

Based on the Axiom of Dominance "Prospect theory under uncertainty" could restrict a set element *B* to

$$\Omega = \{(m, M) \in \Theta \times \Theta : m \preceq M\}$$

where *m* and *M* denote the worst and the best consequence in the set element *B*, respectively. In this case our descriptive model is reduced to

$$V = w'(\mu) v^*(\Omega)$$

Suppose we look at a pessimism index, $\alpha(m, M)$ such that the following two alternatives are indifferent.

Alternative 1. **One can receive *m* for the worst case and *M* for the best case. There exists no other information.**

Alternative 2. **One receives *m* with probability $\alpha(m, M)$ and receives *M* with probability $1-\alpha(m, M)$, where**

$0<\alpha(m,M)<1$.

If we incorporate this pessimism index $\alpha(m, M)$, the value function is obtained as

$$v^*(\Omega) = v^*((m, M))$$

$$= \alpha(m, M)v'(m) + \{1-\alpha(m, M)\}v'(M)$$

Prospect theory under uncertainty (4)

If B_j **includes more than two elements, we use value function**

$$v^*(B) = h(B\,|\,\alpha) = \begin{cases} a + be^{-c\alpha} & \text{If } \; v(g) \neq \dfrac{v(M)+v(m)}{2} \\ a + b\alpha & \text{if } \; v(g) = \dfrac{v(M)+v(m)}{2} \end{cases}$$

Unknown parameters a, b, c **are decided by**

$$h(B\,|\,0) = v(M), \quad h(B\,|\,0.5) = v(g), \quad h(B\,|\,1) = v(m)$$

g **: the imaginary element whose value is equal to the average values of** $B.$

Scenarios

- < Scenario I >

  Each company reduces its emissions by the carbon tax only.

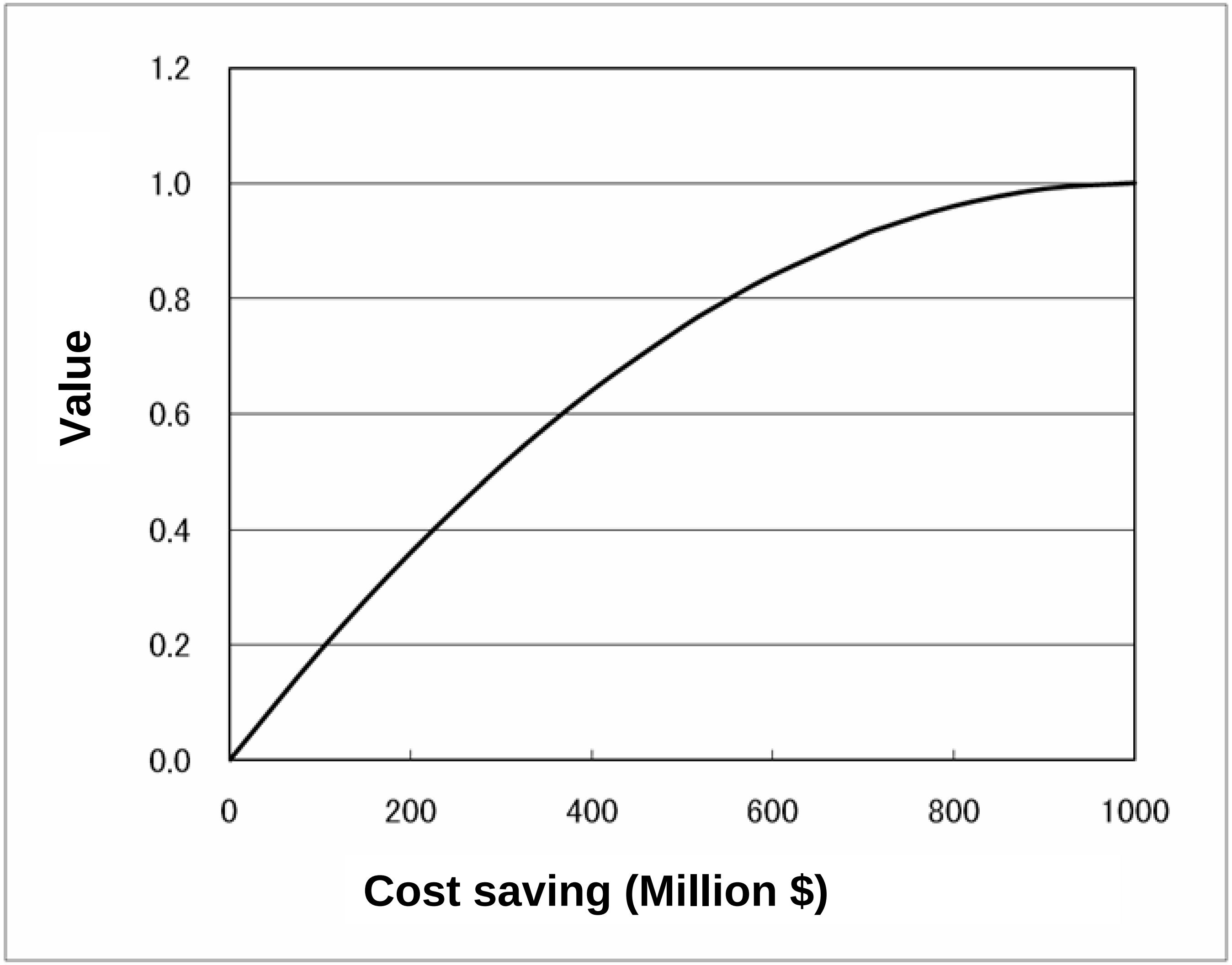
- < Scenario II >

  Each company reduces its emissions by the carbon tax and the emissions trading.

Cost evaluation for Scenario 2

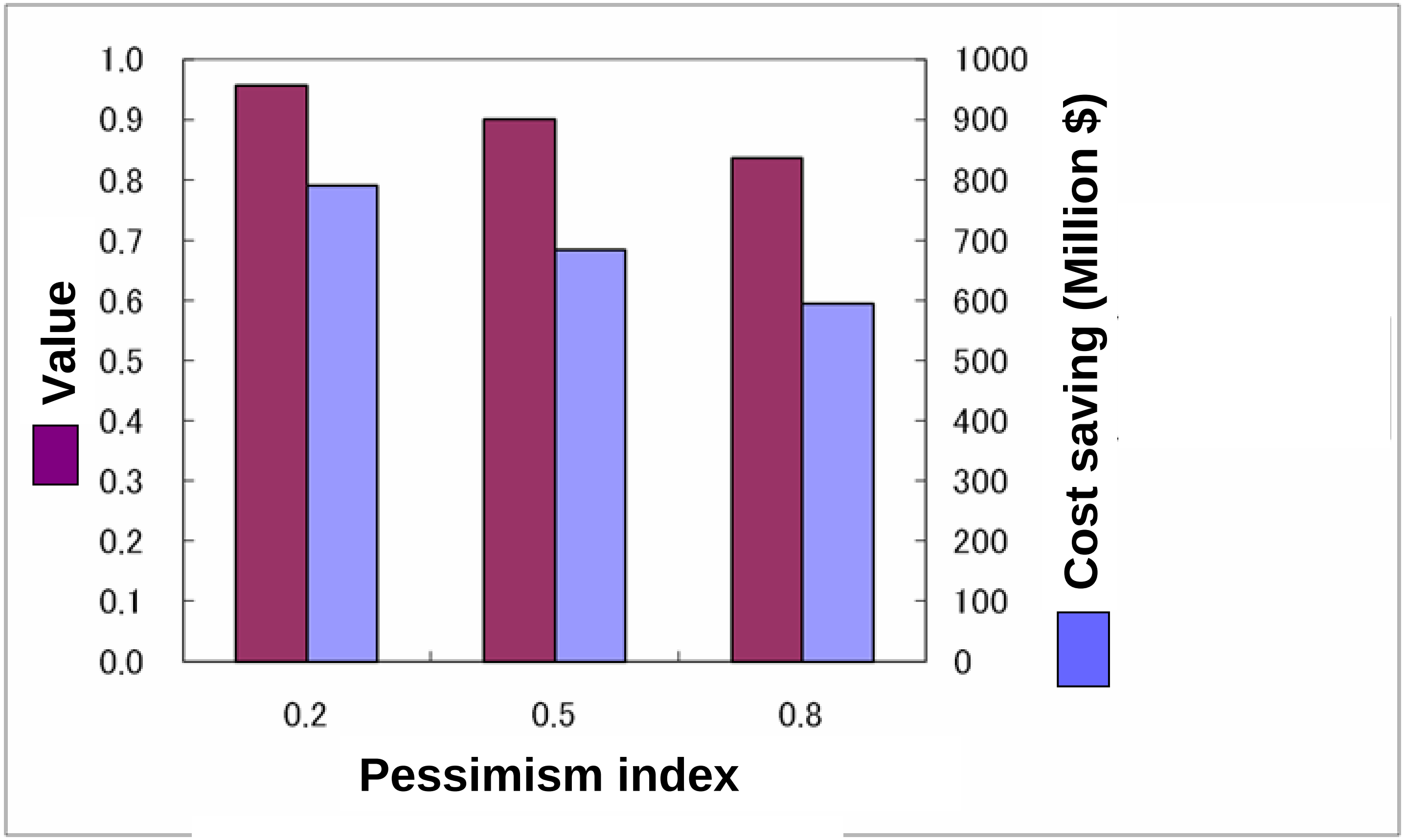
	Co. A	Co. B	Total
Unit Cost for reducing CO_2 ($/t-C)	300	200 220 240	—
Nec. Reduction (Mt-C)	9	0	9
Real reduction (Mt-C)	0	9	9
Cost for reduction (Million $)	0	1,800 1,980 2,160	1,800 1,980 2,160
Trading cost (Million $)	2,250 2,340 2,430	-2,250 -2,340 -2,430	0 0 0
Compliance cost (Million $)	2,250 2,340 2,430	-450 -360 -270	1,800 1,980 2,160

Value function



Simulation results

Value for Scenario 1 is equal to 0. (Reference point)



Value for Scenario 2

Conclusion

- **Attaining reduction target of CO_2 by carbon tax only may lead to too much CO_2 cost.**
- **By introducing emission trading we could reduce CO_2 cost.**
- **Prospect theory under uncertainty would make it possible to evaluate policies of reducing CO_2 emissions for decision makers with different emotion (pessimism index).**

Further research

- Evaluation of economic influence when we use income of carbon tax as earmarked funds instead of general funds.
- Modeling of concrete hybrid policy of carbon tax and emission trading to find an appropriate level of carbon tax.
- More applications of behavioral (emotional) economics to global environmental problems.

The End

Thank you for your attention.